Human Movement Science 34 (2014) 164–177

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Development of interactions between sensorimotor representations in school-aged children

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ARTICLE INFO

Article history:
Available online 15 March 2014

PsycINFO classification:
2330

Keywords:
Motor adaptation
Kinesthesia
Proprioception
Internal models
Motor development
Motor processes

ABSTRACT

Reliable sensory-motor integration is a pre-requisite for optimal movement control; the functionality of this integration changes during development. Previous research has shown that motor performance of school-age children is characterized by higher variability, particularly under conditions where vision is not available, and movement planning and control is largely based on kinesthetic input. The purpose of the current study was to determine the characteristics of how kinesthetic-motor internal representations interact with visuo-motor representations during development. To this end, we induced a visuo-motor adaptation in 59 children, ranging from 5 to 12 years of age, as well as in a group of adults, and measured initial directional error (IDE) and endpoint error (EPE) during a subsequent condition where visual feedback was not available, and participants had to rely on kinesthetic input. Our results show that older children (age range 9–12 years) de-adapted significantly more than younger children (age range 5–8 years) over the course of 36 trials in the absence of vision, suggesting that the kinesthetic-motor internal representation in the older children was utilized more efficiently to guide hand movements, and was comparable to the performance of the adults.

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http://dx.doi.org/10.1016/j.humov.2014.02.001
0167-9457/

1. Introduction

To perform goal-directed arm movements, the central nervous system needs to integrate information about target location and arm/hand location in order to compute motor commands that drive the limb to the desired goal. It is widely accepted that movements are encoded in vectorial space (Buneo, Jarvis, Batista, & Andersen, 2002; Georgopoulos, Schwartz, & Kettner, 1986; Pouget, Ducom, Torri, & Bavelier, 2002), based on a gaze-centered coordinate frame, mapping visual space onto motor space. These representations are likely multisensory in nature, with coordinate frames sharing visual, kinesthetic, and auditory modalities (Fiehler, Rösler, & Henriques, 2010; Henriques, Klier, Smith, Lowy, & Crawford, 1998; Kagerer & Contreras-Vidal, 2009; Pouget et al., 2002). Planning and execution of limb movements usually involves visuo-kinesthetic information, such as coding of initial hand position, and of the evolving state of the effector. Previous research has proposed that both (hypothetical) visual and proprioceptive movement vectors are likely fused at their origin (Rossetti, Desmurget, & Prablanc, 1995; Yan, Thomas, Stelmach, & Thomas, 2000), providing us with an integrated and optimal estimate of where the end effector is in space (van Beers, Wolpert, & Haggard, 2002). At the same time, the two sensory inputs are weighted depending on task demands, such that in the absence of vision the system up-weights sensory input from kinesthesia in order to optimize movement control processes and enabling us to reach toward targets without vision of the effector (Fiehler et al., 2010; Henriques et al., 1998; Rossetti et al., 1995).

Previous research has examined sensorimotor integration in young to middle-aged adults where it is reasonable to assume that mechanisms pertaining to sensorimotor integration, and the resulting formation of internal models, are relatively stable. This is not true for children whose motor performance is generally less accurate and more variable than adults (Contreras-Vidal, Bo, Boudreau, & Clark, 2005; Yan et al., 2000), and improves as a function of age. This has been shown not only for visually guided drawing tasks (Contreras-Vidal et al., 2005; Ferrel-Chapus, Hay, Olivier, Bard, & Fleury, 2002), but also for force adaptation (Konczak, Jansen-Osmann, & Kalveram, 2003), or postural tasks in infants (Chen, Metcalfe, Jeka, & Clark, 2007). One possible explanation for this higher variability in children is that sensorimotor internal models in children are not yet as well 'tuned' as they are in adults; this might be due to increased noise in the sensory and motor systems, or to increased noise in the integration process itself, or to a combination of these factors. The first option, that internal models can be expected to become less accurate when the unimodal input itself is not well defined, is supported by a recent study in 7–13 year old children, testing the accuracy of the unimodal estimates of vision and proprioception. Using a localization task, the study showed that proprioceptive-based estimates become increasingly more reliable in older children (King, Pangelinan, Kagerer, & Clark, 2010; Pickett & Konczak, 2009); as a result, younger children up-weight visual information, whereas older children up-weight proprioceptive input when task demands require this. An earlier study in 5–11 year old children using a localization task in connection with a tendon vibration perturbation (Hay, Bard, Ferrel, Olivier, & Fleury, 2005) showed an interesting pattern of movement amplitude accuracy: constant amplitude errors showed a U-shaped function of age, with the highest accuracy at 5 and 11 years of age, and lower accuracy at 7 and 9 years. The authors attributed the lower spatial error in the young children to their successful use of feedforward control, and that of the older children to their increased integration of proprioceptive feedback processes, whereas the younger children were more dependent on visual feedback processes. Variability of the amplitude error showed a linear decrease with age, speaking to the generally higher noise in the developing motor system of young children.

Using a kinesthetically-guided center-out reaching task in 6–10 year old children, Contreras-Vidal showed that the 6-year-olds performed with larger endpoint errors when they had to rely on kinesthetic feedback than the 10-year-old children, suggesting a less well defined kinesthetic-motor internal representation in the younger than in the older children or the adults, affecting predominantly movement execution (Contreras-Vidal, 2006; van Beers et al., 2002). Overall, these findings indicate that the acuity of proprioceptive or kinesthetic estimates, and their integration with other modalities increases with age (Bo, Contreras-Vidal, Kagerer, & Clark, 2006; Smits-Engelsman & Duysens, 2008;